(NASA-CR-157066) SILICON SOLAR CELLS WITH A TOTAL POWER CAPACITY OF 30 KILOWATTS Final Technical Report (Solarex Corp., Rockville, Md.) 17 p HC A02/MF A01 CSCL 10A

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FINAL TECHNICAL REPORT, REVISED

JPL Contract No. 954577

DRD No. MA 006

Silicon Solar Cells with a Total Power Capacity of 30 Kilowatts

SOLAREX CORPORATION
Rockville, Maryland

PROJECT: Large Scale Production Task

October 31, 1977

PROGRAM HISTORY
(Contract No. 954577)

INTRODUCTION

Solarex Corporation began work on this contract on August 26, 1976. The contract called for Solarex to "Design, develop, manufacture, test and deliver a quantity of solar cell modules capable of providing 30 kilowatts of power." These solar modules were to comply with the requirements of JPL Document 5-342-1 entitled "Silicon Solar Cell Module Performance, Environmental Test and Inspection Requirements," dated May 27, 1976.

The bulk of the contract effort was carried out in the following two phases:

PHASE I --- Module Design, Pre-production Module Fabrication, Inspection and Test.

PHASE II -- Production, Test and Delivery.

Other items in the Statement of Work required Solarex to implement a JPL-approved Inspection System Plan to verify the manufacturing processes assembly and tests; and to provide other items of engineering and administrative documentation. In addition, Solarex responded to twelve Unilateral Modifications to the contract.

Effort during the first two months of the contract concentrated on design of a solar module to meet JPL specifications. Basic module design resulting from this effort is as follows:

1. Frame Design --- Solarex chose a 23" x 23" module size thus forming a 2 x 2 pattern for the module sub-arrays. An alloydyned aluminum frame was designed to both satisfy the basic loading requirement of ± 50 lbs. per square foot and to provide a lightweight, weatherable frame.

2. Cell Pan Design --- Key design problems were to develop a cell pan/potting surface that would meet the basic design objectives and also provide for the required electrical isolation. While various materials were examined and tested, the increased electrical isolation requirements that were part of Unilateral Modification No. 1 led Solarex to select a polyester substrate with aluminum edge retention strips as a basic cell pan assembly.

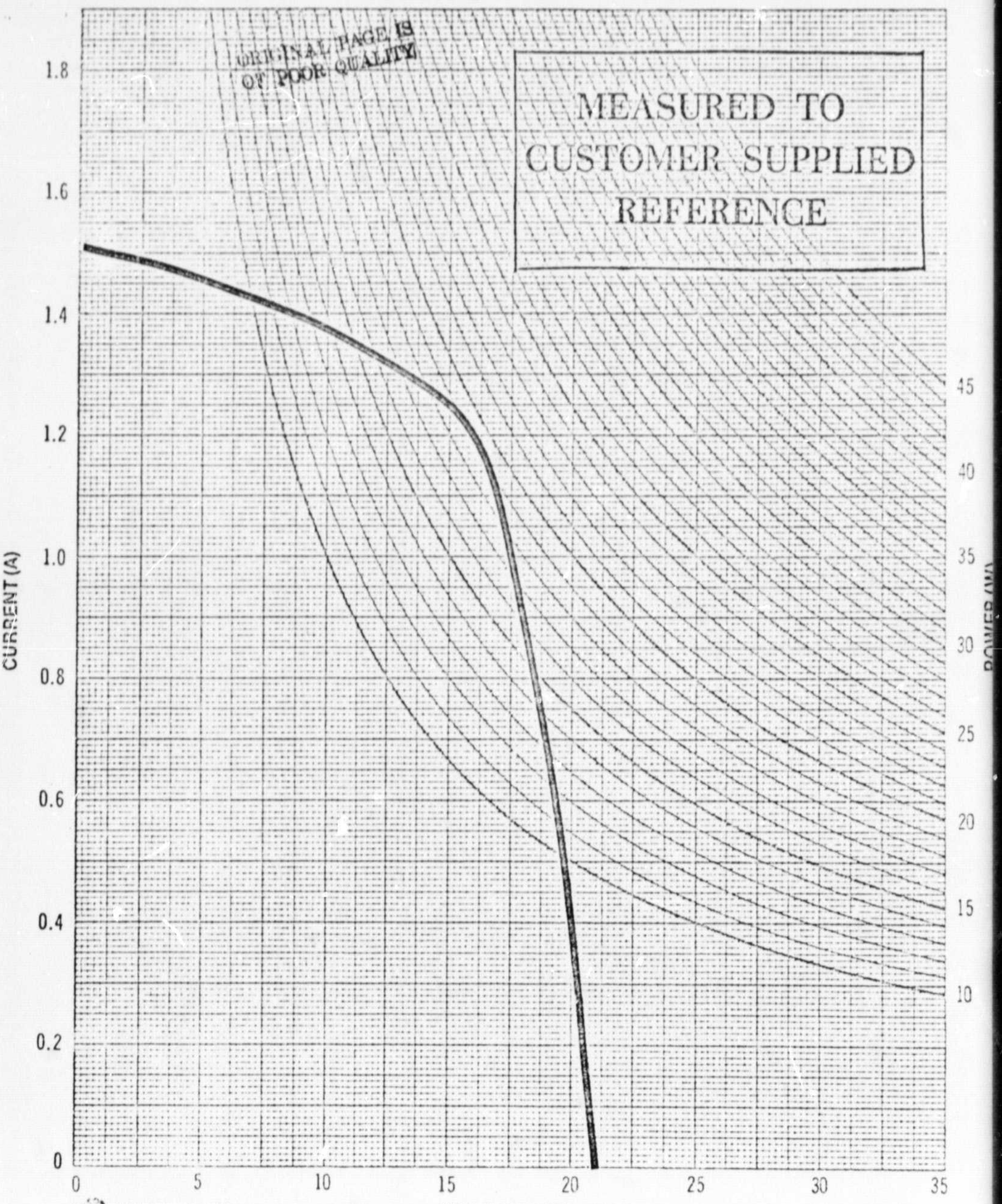
3. Cell Interconnection --- Solarex utilized forty-two three inch diameter cells, arranged in six rows with seven cells per row to achieve the required minimum of 15.8 volts at 60°C. A new photolithography mask pattern was generated for these cells. This pattern has fine gridlines, dual interconnect pads and is designed for optimum 60°C performance. The cells are solder-connected in a single series string. Tinned copper tabbing strips are utilized as the cell-to-cell interconnect material within

each row. Rows of cells are electrically connected by soldering the tabbing strips at both ends of each to tinned phosphorus bronze sub-busses. The ends of the series string are fed through the polyester substrate directly into junction box mounted on the back of the module. A five terminal, twin screw thermoplastic terminal block, rated at 1500 Volts, was used as the connector within the junction box.

4. Encapsulation --- Solarex selected a cell encapsulation system which is based on complete conformal casting with silicone rubber. The conformal casting eliminates any difficulties at the solar cell interfaces since the strings of cells are actually floating in the pliable rubber. Silicone rubber's high transmittance and impact resistance and Solarex's nearly four years of field experience with it were the primary factors in its selection.

5. Electrical Performance --- A forty-two cell series string of Solarex's 3" chevron cells exceeded the initial contract power requirement of 60 Watts per four module sub-array. At 60°C, Solarex 3" diameter chevron cells show a minimum average photovoltage of 380 mV at the power peak. Thus with 42 cells in series, a minimum voltage of 15.96 Volts may be obtained for each module at its peak power. Under this contract, delivered power was measured at 15.8 volts. At this voltage, Solarex modules should produce more than 18.5 Watts. Thus, at four modules per sub-array a total of 74 Watts is obtained, exceeding the 60 Watt minimum requested. An I-V plot showing typical power produced at 60°C is shown in Exhibit I.

EXHIBIT 1



SOLAREX

Panel Type JPL9200 Serial No. TYPICAL Temp. 60°C Date 15 MAR 77 By

On October 25, 1976, Solarex personnel discussed the above and other items including the Inspection System Plan at a Preliminary Design Review held at JPL. Action items resulting from that design review are as follows:

	ACTION ITEM	ORGANIZATION	RESOLUTION
1.	Supply wire size and type to be used to connect modules in demonstrations.	JPL	Info. Supplied
2.	Supply optical property data for various aluminum frame finishes.	JPL	Info. Supplied
3.	Consider revision of mounting pattern dimensions and tolerances on module frame.	Solarex	Dimensions and tolerances revised
4.	Revise Terminal Block and J-Box design to meet requirements of 5-342-1, Rev. A.	Solarex	Design Revised for easier access to terminal block.
5.	Revise top assembly and interface control drawings to reflect changes and additional info. required.	Solarex	Drawings Revised

During early November Solarex completed work on several action items resulting from the October design review. Later in the month Solarex began work on the required pre-production modules. The first ten were completed by mid-December and subjected to the environmental tests as described in JPL 5-342-1, Revision A. The temperature and humidity cycling tests were performed by the General Environments Corporation in Hartwood, Virginia. A report summarizing these tests is included in the Appendix. Mechanical loading, electrical iso-

lation tests were performed at Solarex. No significant changes in performance were observed.

In early January an additional ten pre-production modules were shipped to JPL for qualification testing. On January 26, 1977, the Pre-production Design Review was held at Solarex. This meeting reviewed the module design, inspection system plan, 60°C temperature correction factor and standard solar cells in light of the recently completed pre-production module manufacturing and environmental testing. Since all phases of module design had been discussed at the Preliminary Design Review and pre-production modules had successfully completed environmental testing, major discussion centered around specific items in the above areas that had to be resolved prior to the start of production. These resulted in the following Solarex action items:

	ACTION ITEM	RESOLUTION
1.	Verify cycle time, temperature and rates for thermal and humidity cycles.	Data provided.
2.	Verify availability and calibration of new electrical isolation equipment.	Information provided.
3.	Analyse I-V curves for modules sent to JPL to determine temperature correction factors.	Solarex performed acceptance testing at both 60°C and OTC using JPL-supplied Y-standards.
4.	Verify comparison of Block II "Y" standard with Block I standard.	Data provided. Block II "Y" standard showed short circuit current 6.4% less than Block I standard.
5.	Update all drawings and submit reproducibles to JPL.	Drawings updated and submitted.

6.	Incorporate agreed upon changes in Inspection System Plan.	Changes relating primarily to workmanship standards, in process inspection and changes in measurement and testing required by 5-342-1, Rev. B were incorporated.
7.	J-Box Grounding.	Existing J-Box termination considered acceptable by NASA-Lewis.
8.	Provide method of assuring positive grounding of 4th side on edge retention strip.	Ground screw was added to fourth side to assure positive grounding.
9.	Submit detailed written procedure for electrical performance testing.	Procedure describing equipment set-up, intensity calibration, temperature, actual test procedure and documentation submitted.
10.	Submit isolation test data obtained during Qualification testing and describe actual equipment used.	Data and information provided.

The Design Review resulted in agreement to go into production, pending resolution of the above action items.

The entire month of February was spent resolving action items generated by the pre-production design review. While most items concerning such subjects as grounding, test procedures and drawing revisions were resolved quite easily, the related issues of standard cells and 60°C temperature correction factors proved more difficult. The major reason for this being that two sets of standard cells supplied to Solarex proved to be defective. Correcting the confusion caused by defective standards and performing 60°C measurements required several weeks. Final authorization to submit modules for JPL source inspection was received on March 16, 1977.

PHASE II

Production of Modules began in mid-March with the first shipment being made on March 31. A complete shipment summary is shown in Table I Temperature correction factors based on pre-production modules indicated that average module power (15.8 Volts, 60°C customer-supplied standard) would be 17.55 Watts. However, early production shipments averaged 18.6 Watts per module, resulting in a four module sub-array power of 74.4 Watts.

Some procurement, technical and quality control problems did occur during the delivery. Dimensional variances resulted in the rejection of a significant number of module frames by Solarex incoming Q.C. This problem was most evident during March thru early May. At that point Solarex added an additional frame supplier in an attempt to alleviate the problem; nevertheless it continued to occur sporadically throughout the delivery.

In early June corona discharge, indicating inadequate grounding, was observed in JPL dielectric test activities. Investigation showed that the module J-Box was not completely grounded. Manufacturing procedure was revised to include tapping of a machine screw into an undersized hole in the J-Box wall to assure positive grounding.

Early in the delivery (March-April), Solarex experienced some quality problems relating to improper soldering and spacing of cell-to-cell interconnects and soldering of lead wires. These problems were somewhat anticipated since this large a module had not been produced by Solarex before. They were resolved by worker re-training, increased in-line Q.C. and production experience. Later in the delivery (June-July),

there were some Q.C.-problems with respect to microscopic delamination and tiny bubbles in the encapsulant. These problems were jointly resolved by Solarex and JPL Q.A. personnel. Issuance of a Technical Direction Memorandum revising rejection criteria eliminated this problem.

In late July Solarex received a unilateral modification to the contract to perform destructive pull testing experiments on ninety regular production solar cells. JPL provided a Unitek pull tester on which to perform the tests. The tests were conducted from July 26 to August 16 and are summarized as follows:

TYPE OF CONTACT	TOTAL SAMPLE SIZE	MEAN PULL STRENGTH	STD. DEV.
Front Cell Surface	90	518 grams	226
Back Cell Surface	90	653 grams	236

As shown above, the mean pull strength for tabs on the back cell surface is significantly higher than on cell front surfaces. This results from the additional area available for soldering on the back, non-illuminated surface of the cell. Additional analysis indicated that mean pull strength on the left tab (front and back) was slightly higher (less than 5%) than the right tab. Analysis of cumulative results by individual operators indicated that pull strength did vary somewhat (within one standard deviation) from operator to operator.

Final shipment under this contract was made on August 31. A total of 1585 production modules were shipped under this contract.

During July Solarex decided to offer the module developed under this contract to its commercial customers. A data sheet with photos and performance characteristics of this Type 9200J panel is included in the Appendix.

FUTURE COST REDUCTION AREAS

On numerous occasions Solarex officials have publicly recommended various government initiatives to reduce the future costs of solar cell production. Recommendations in the following areas relate to future JPL activities:

1. Future Solar Cell Purchases --- To the maximum extent possible, future government purchases should be timed and sized in such a manner that they push the industry to add production capacity. Larger quantity, multi-year buys are the best method to accomplish this. In addition, excessive contract modification resulting in numerous delays and bureaucratic problems should, to the maximum extent possible, be eliminated.

2. Inexpensive Silicon --- Much cheaper silicon is an absolute necessity if DOE cost reduction goals are to be met. Current JPL-funded laboratory efforts must be reviewed to determine when they will be feasible as production technologies. Promising near-term technologies not currently receiving government support, such as cost silicon, should be funded on an accelerated basis.

3. Automation & GFE --- Significant cost reduction in solar cell manufacturing will occur as the cell makers automate their manufacturing facilities. While government purchases provide some capital for investment in plant and machinery, this process could be vastly accelerated if the government began applied engineering efforts addressing the problems of automating the current technology and provided government-furnished equipment to be used for automated production.

APPENDIX

A. Type 9200J Unipanels

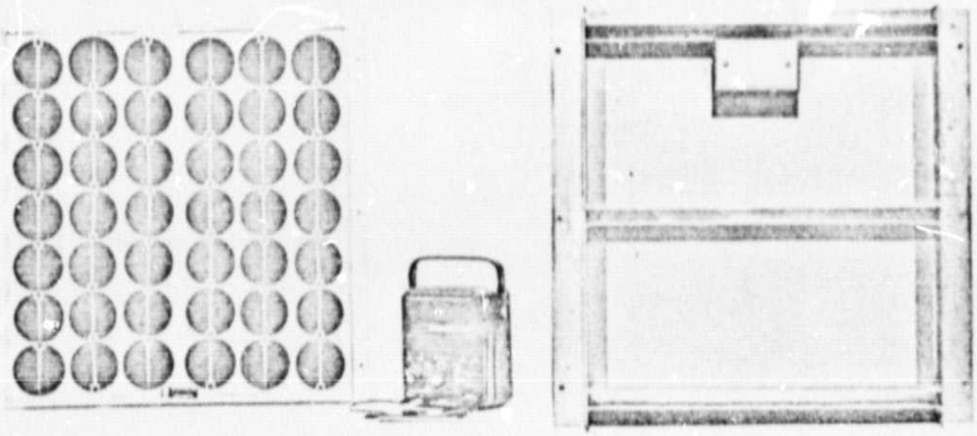
B. General Environments Corporation

Solarex

SOLAREX CORPORATION
1335 PICCARD DRIVE
ROCKVILLE MD 20850
(301) 948-0202
TWX 710-828-9709
CABLE ADDRESS: SOLAREX

ORIGINAL PAGE IS OF POOR QUALITY

SOLAREX® SOLARVOLTAICS ™ FOR SOLAR ELECTRICITY TYPE 9200J UNIPANELS®



The Solarex Corporation Type 9200J solar electric panel was designed and tested especially for the Jet Propulsion Laboratory as part of ERDA's Large Scale Production Low Cost Silicon Solar Arrays.

FEATURES

- 42 Three-inch diameter high efficiency silicon solar cells connected in series featuring:
  - Unique corrosion resistant Trimet™ contacts (electrodes)
  - Tantalum oxide anti-reflection cell coating
  - Redundant interconnections
  - "Starship" finger pattern with fine line structure and double solder pads.
- Cells mounted on a polyester board and fully encapsulated in a special stabilized silicone rubber to provide a transparent, weather resistant, and corrosion-free package.
- Allodyned aluminum integral mounting frame. On reverse side is a sealed junction box.
- Extensive in-house quality control and testing throughout panel manufacture.

ELECTRICAL PERFORMANCE

Type 9200J Unipanel	60°C	28°C
Watts (peak) *	20	23
Amps @ V nom.	1.3+	1.3+
Ah/Week **	40	40
Wh/Week **	600	690
Voltage @ peak power	16	19
V_{oc}	21	24

* Typical output at maximum power point in full sun ($100 mW/cm^2$) at 28°C.

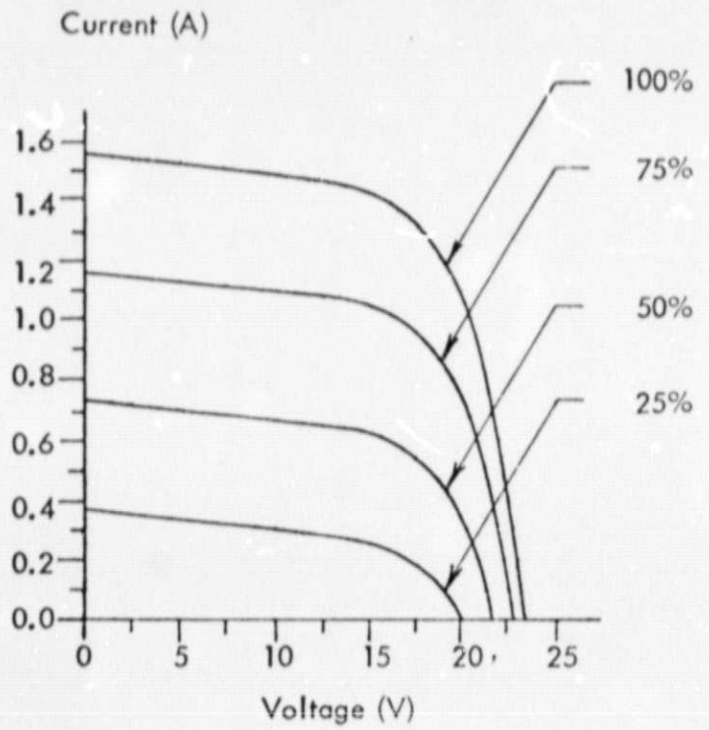
** Typical output based on U. S. average insolation.

+ 60°C 16V nom.
  28°C 19V nom.

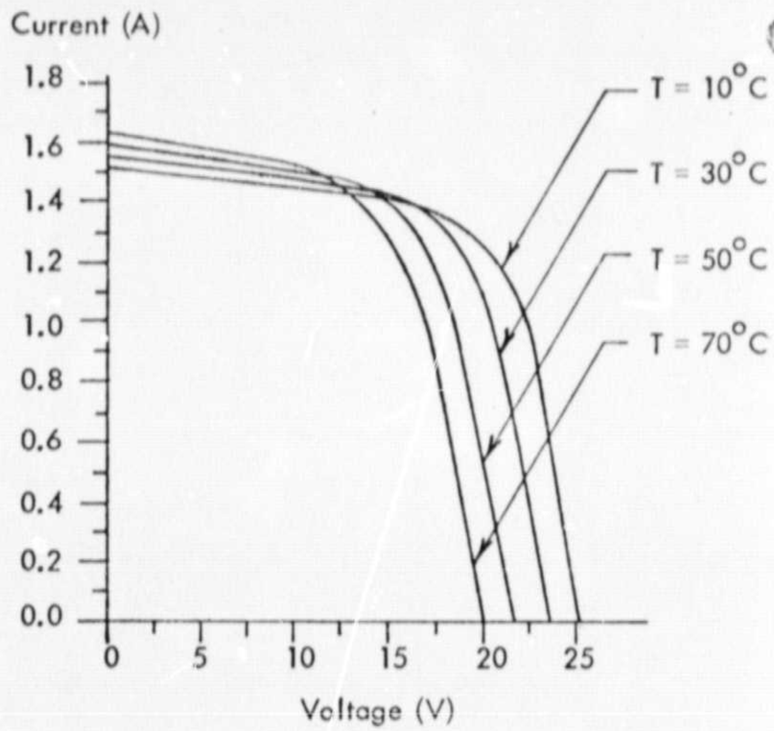
Meets personnel safety requirements; at least 100 megaohms isolation resistance from ground, tested at 1500 Volts.

SOLAREX TYPE 9200J UNIPANEL®

TYPICAL CURRENT/VOLTAGE CURVES



Panel Performance for Varying Sunlight Intensities at 28°C



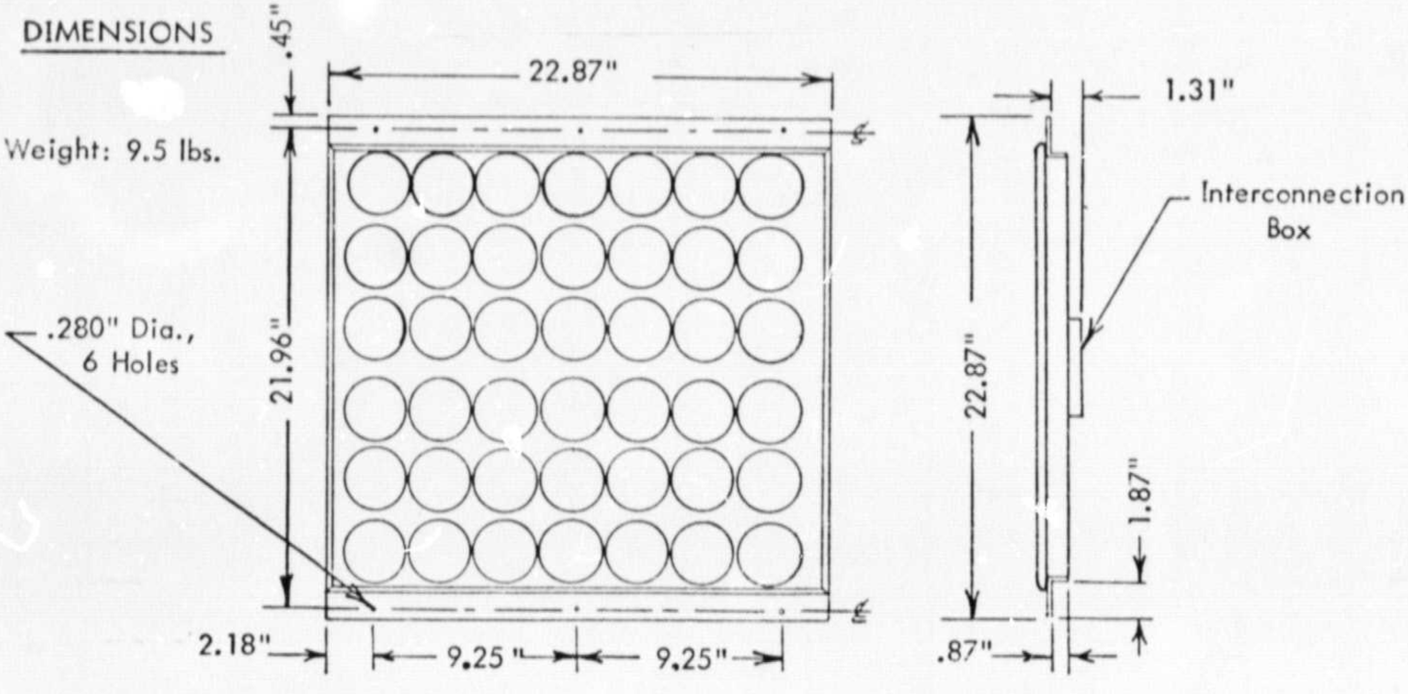
Panel Performance for Varying Termperatures at AM1 (100mW/cm^2)

ENVIRONMENTAL SPECIFICATIONS (Meets JPL Environmental Performance Requirement No. 5-342-1 Rev. B)

- Thermal cycled from -40°C to +90°C. No performance degradation.
- Humidity cycled 7 days @ 95% relative humidity at elevated temperatures. No performance degradation.
- Wind loading toleration when mounted 200 lbs./ft^2 front or back minimum.

DIMENSIONS

Weight: 9.5 lbs.



INSTALLATION

Designed to be easily mounted individually or in arrays on a frame or structural member.

GENERAL

General Environments Corporation / Hartwood, Virginia 22471 / (703) 752-5361

REPORT

Client: Solarex Corporation
1335 Piccard Drive
Rockville, Maryland 20850

Report No. A-5370
Date 24 January 1977

Subject: Thermal Cycling and Humidity tests conducted on ten Solar Modules in accordance with Solarex Corporation purchase order 3588. Testing was completed 14 January 1977.

1.0 THERMAL CYCLING

Test Facilities

Standard 36FS Thermal Chamber, GEC No. 171D

Test Procedure

The test items were placed within the thermal chamber and subjected to fifty temperature cycles. The temperature was varied between -40°C and 90°C at an approximate rate of 100°C per hour. Each temperature cycle was no greater than six hours long and a cycle was from ambient to 90°C to -40°C to ambient.

Test Results

Twenty-six consecutive thermal cycles were completed. Difficulties with the thermal chamber made it necessary to discontinue the test to affect repairs to the chamber. Following the completion of thirty-one thermal cycles the cognizant Solarex, Corporation representative removed the test items from the thermal chamber for visual and electrical inspections. The test items were then replaced and twenty-eight consecutive thermal cycles completed at which time the test was concluded with a total of fifty-nine thermal cycles being completed. Recordings of the temperature generated during the thermal cycling test are enclosed. The temperature recordings are in °F. A photograph of the test arrangement is enclosed.

2.0 HUMIDITY

Test Facilities

Guardite Humidity Chamber, GEC No. A102D

Test Procedure

The test items were placed within the humidity chamber and subjected to the following conditions. The internal chamber temperature was adjusted to 54°C and maintained for twenty-four hours as a pre-drying cycle. The internal chamber was then adjusted to 23°C with 50% relative humidity and maintained for twenty-four hours. The internal chamber temperature was then increased to 40.5°C and 90 to 95% relative humidity over a two hour time period, maintained at 40.5°C and 90 to 95% relative humidity for a sixteen hour time period, the temperature was then decreased to 23°C and 90 to 95% relative humidity over a two hour time period and maintained at 23°C and 90 to 95% relative humidity for a four hour time period which constituted one twenty-four hour varying temperature and humidity cycle. This cycle was repeated for a total of five twenty-four hour cycles.

Test Results

On three occasions the pneumatically controlled temperature and humidity recorder indicated erratic conditions. However, the chamber conditions were stable and there were droplets of moisture accumulating in the air line supplying the recorder. Recordings of temperature and humidity generated during the humidity test are enclosed. The temperature recordings are in °F. The recording chart is 0-200°F dry and 0-25°F differential. A photograph of the test arrangement is enclosed.

GENERAL ENVIRONMENTS CORPORATION

APPROVED Roger Cook
Roger Cook

BY Aubrey A. Ellis
Aubrey A. Ellis